

Validation of an ontology of risk and disaster through a case study of the 1923 Great Kanto Earthquake

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Abstract— This paper seeks to validate a factual ontology derived from an ontology of the domain of risk and catastrophe (Provitolo, Müller, Dubos-Paillard, 2009). The factual ontology is that part describing the structure and dynamics of the system, that is, the representation of an event and of on what it has a bearing. The objective is to show that the ontology is able to account for and allow comparison between complex stories (because of the diversity of event types and of their multi-scale description). The event used as the basis for validation of the ontology is the Great Kanto Earthquake of 1923. The account is that of P. Hadfield (1991) that provides a detailed description of the earthquake. Judgements by the actors involved of the system elements and events are excluded from this exercise, which is a first stage in validating the ontology.

Index Terms— instantiation, Kanto earthquake, modelling, ontology of disaster, validation

I. INTRODUCTION

IN the field of risk and catastrophe, a great deal of research has been conducted into the concepts [1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11] and the analysis of accidents or catastrophes. On the basis of that work, we have proposed a formalized ontology of risk and catastrophe [12].

The most common definition of an ontology is that of [13] who defines it as a specification of the conceptualization of a domain. An ontology is therefore a structure for describing knowledge in a given field. A distinction is generally drawn between the conceptual ontology defining the terminology employed and the concrete ontology, which uses that terminology to describe an actual situation. The formalized ontology that we proposed [12 op. cit.] is essentially a conceptual ontology in which we distinguish the terminology used to depict what happened (e.g. 30 died on some bridge) from the characterization of what happened (there has been an accident, a serious accident or catastrophe) from the standpoint of the various actors of the system.

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Here we begin with this formalized ontology and look more especially at the part describing the system's structure and dynamics. Henceforth we call this the factual ontology as it allows us to describe what happened without taking up any particular standpoint.

The overall aim of this factual ontology is to be able to handle stories made complex by the diversity of types of events and their multi-scalar character. A conceptual framework needs to be provided within which to analyse the various types of events, whether localized or dispersed, natural, industrial/technological or social. This factual ontology purports also to be suitable for studying events on different scales (micro, meso, macro). This should make it easier both to put into perspective different events that *a priori* share few common features, and to come up with a method for comparing events.

The paper aims first to validate such an ontology by instantiating it based on the factual description of an event: the Great Earthquake of Kanto of 1923 as related by P. Hadfield [14]. This concrete case was chosen because the account mostly describes facts and not standpoints or judgements of those facts by those involved. We are looking here, then, at the representation of the story. This will allow us both to test out our factual ontology and to question the validation process of this sort of ontology.

II. A FACTUAL ONTOLOGY OF RISK AND CATASTROPHE

Factual ontology is that part that allows us to describe the structure and dynamics of a system. As stated in the introduction, the factual ontology is a part of the conceptual ontology of risk and catastrophe presented in [12 op. cit.]. The conceptual ontology enabled us:

- to return to the essential concepts allowing us to characterize risk, accident, catastrophe and the associated notions and to organize these concepts in terms of the relations among them;
- to identify four subsystems making up the conceptual model: *Structure*, *Dynamics*, *Actor* and *Characterization* (Fig. 1). The *Characterization* subsystem enables us to specify how different actors characterize the system's structure and dynamics.

In this paper we propose an initial validation of the structure and dynamics part of this ontology based on the account by P.

Hadfield [14 op. cit.] of 'The Great Kanto Earthquake' by reproducing the account using the concepts of this ontology. Actor judgements of the system's elements and events are excluded from this first validation exercise.

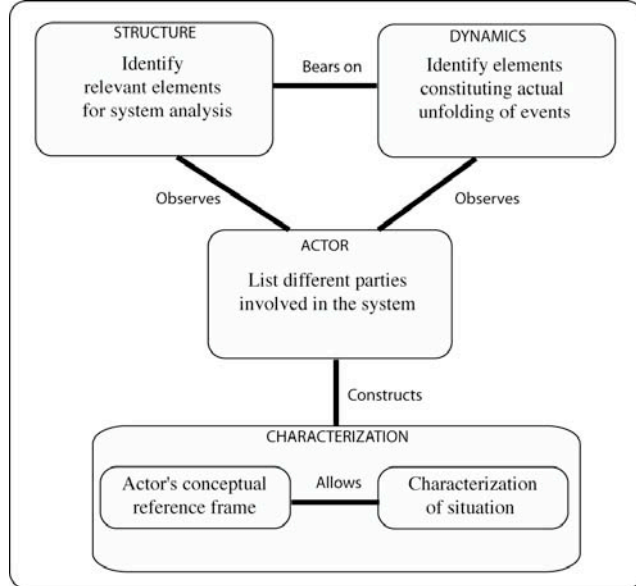


Fig. 1. Systemic division of the meta-model into four subsystems

We therefore present only the Structure and Dynamics subsystems of the conceptual model of risk and catastrophe. This model has been represented by UML (Unified Modelling Language) class diagrams [15]. Ontologies do not have standard graphical means of representation although a graphic depiction is often a very powerful means of communication. UML provides such representations and especially class diagrams representing concepts and their attributes by rectangular boxes and relations between concepts by arrows. Two types of relation are distinguished: the generalization/specialization relation for expressing that one concept is more general/more specific than another (arrow with white triangle pointing to the more general concept) and the semantic relations bearing the name of the relation and the associated cardinalities (how many objects may be related to how many others).

In what follows, we begin with the ontology (and therefore the class diagram) proposed in [12 op. cit.] that we specialize to take account of the specific account. For example, the general notion of event will be specialized into collapse, fire, etc. as particular cases of events.

Thereafter we shall instantiate these notions to reproduce the account proper. Thus, several cases of collapse are mentioned in the account and shall therefore be so many instances of the general notion of collapse. Another UML diagram -the object diagram- shall be used to depict these instances and their structural and temporal linkages. An object diagram represents each instance by a box mentioning the instantiated notion possibly with a name by which to identify it and each connection by an arrow. These connections are

themselves instances of semantic relations between notions. For example, it can be said in conceptual terms that one event may cause another (that there is a semantic relation of cause and effect between events) and the connections will be able to express which events actually did cause other events according to the account.

A. The structure of the system

The *Structure* identifies the relevant elements for analysing a system open to potentially catastrophic events. The elements are the parts forming the system's structure (Fig. 2). The system is open to its environment (in the systemic meaning of the term). It is therefore also composed of exogenous elements that are by definition outside of the field of study. The 'Element' class generalizes the 'Living Element', 'Physical Element', 'Organization' and 'Infrastructure' classes that appeared to us to be the relevant categories to be distinguished in the case of risk and catastrophe:

- living element includes all human beings and natural populations such as plants and animals;
- physical element corresponds to the description of the earth's surface (oceanography, hydrography, pedology, relief, etc.) and does not directly pertain to human activities;
- organization is a structure for responding to needs and achieving set objectives. Organization integrates systems for preventing and managing events.
- miscellaneous infrastructures encompass built areas, facilities, networks, etc.

Instantiating the conceptual model has required the inclusion of new relations:

- the first to indicate that a system may be a particular case of an element. Adding this relation makes it possible to represent the interleaving of spatial levels (scale) within a system (systems are thus composed of systems, which are themselves made up of systems, etc.);
- the second to indicate the existence of neighbourhood relations between elements of the system. The concept of neighbourhood refers to a topological space. It provides more possibilities than the simple use of distance between spatial entities (metric space). It allows us to form spatial subsets by neighbourhood (first-, second-order continuity, etc.). We shall see that this neighbourhood relation allows us to make a territorial analysis of the event, or more accurately the series of events, that occurred in the city of Tokyo.

This first instantiation therefore enhanced the structure of the system.

The system structure is related to the dynamic subsystem since both events and damage bear on the 'element' class.

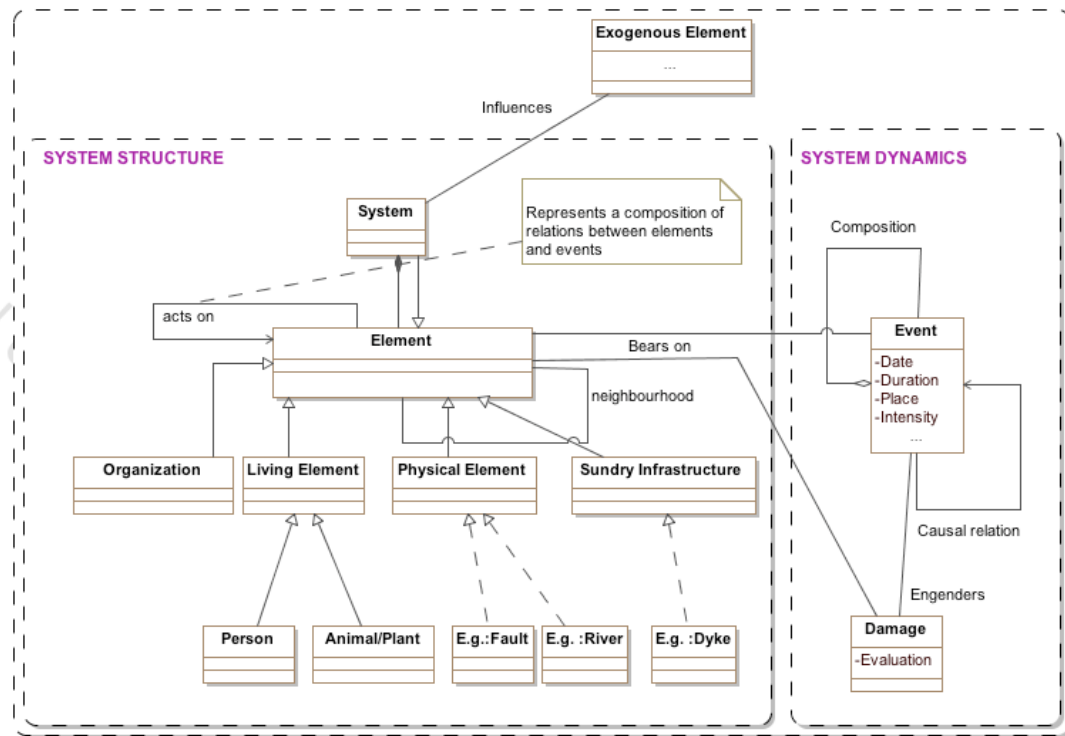


Fig. 2 The system structure and its relations with the dynamic subsystem

B. System dynamics

Just as the system structure is composed of elements, the system dynamics (Fig. 3) is composed of elementary structures in the form of events. Each event may be ascribed a date (at a given level of granularity) and a duration. Each

event may be made up of events, which provides an understanding of the interleaving of temporal levels in the event structure in parallel with the interleaving of spatial levels.

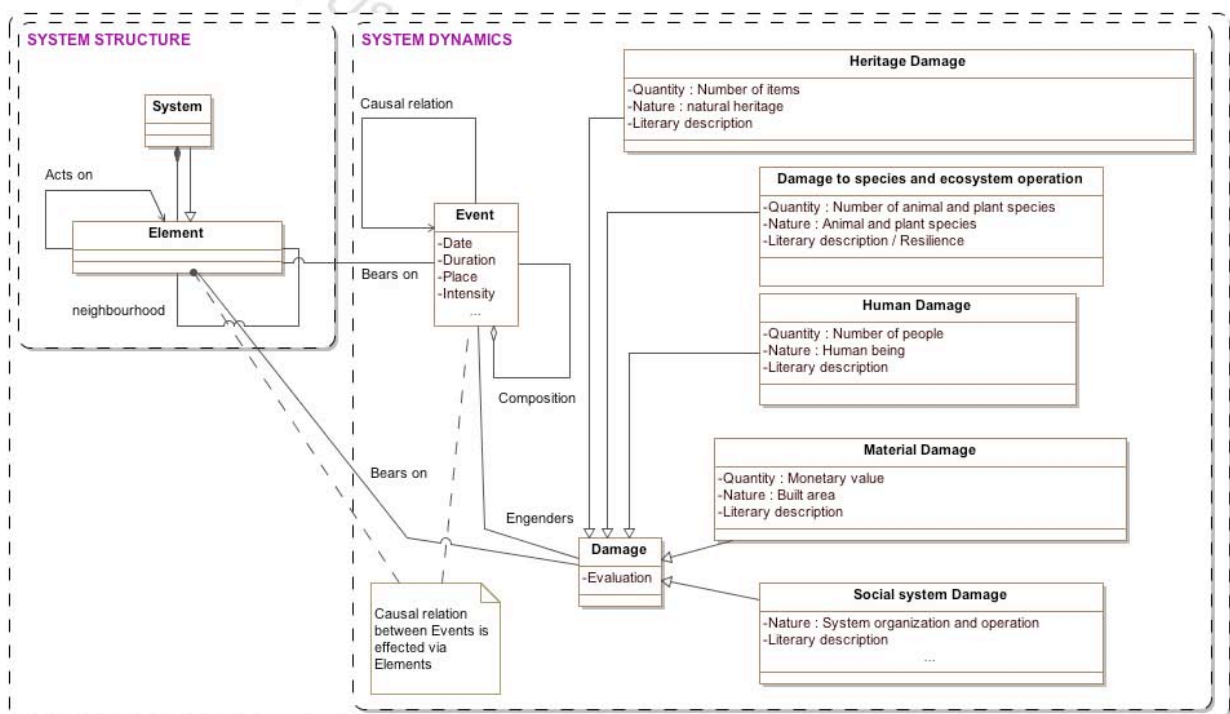


Fig. 3 System dynamics and its relations with the Structure subsystem

An event has a bearing on one or more elements of the system. The ‘bears on’ relation allows us to make a link, the cogwheel between event and an element. Elements are in fact nothing other than the ‘matter’ of which events are part.

An event may also cause another event. Events are then tied to each other by causal relations that are achieved via elements: one speaks of causal chains between events. This causal chain corresponds to domino effects that are often cited in the literature on risk and catastrophe, especially by [16]-[17]-[18]-[19]-[20]-[21]. It shall be seen later in this paper that it is a set of causal chains that allows the Kanto earthquake to be characterized as ‘The Great Kanto Earthquake’.

Lastly, the event can engender damage of different kinds and in variable amounts. Damage bears on elements, which explains why the classification of damage is based on that of elements. The classes titled ‘human damage’, ‘damage to species and ecosystem operation’, ‘material damage’, ‘damage to social system’ and ‘damage to heritage’ specialize the ‘Damage’ concept. Such damage may be the subject of quantifications or of literary descriptions. It is generally defined in human or material terms. But it may also bear on economic and financial systems and on heritage whether natural or cultural.

III. INITIAL VALIDATION OF THE FACTUAL ONTOLOGY BASED ON THE ACCOUNT OF THE GREAT KANTO EARTHQUAKE (1923)

The aim is to determine to what extent the ontology developed can account for complete and complex stories (structural complexity related to the variety of type of event, elements, complexity of spatial scales and levels of organization).

In this paper, validation is effected by instantiation on a wealth of situations within the chosen account so as to check whether the model constructed applies to different types of concrete situation. Thus, to test whether the factual ontology is robust, it was instantiated (using *Magic Draw*) from P. Hadfield’s account of the Great Kanto Earthquake of 1923. That account is rich enough for the factual ontology to be tested. It allows it to be tested on a large number of system elements (living elements, physical elements, infrastructure), on different types of event, whether localized (earthquake/natural origin) or widespread (fire/technological origin) and at different spatial scales (cities, districts) and at different levels of organization (population, individual). By contrast, this account makes no mention of the characterization of these events by their various actors.

A. Presentation of the case study: the Great Kanto Earthquake, 1923

The Great Kanto Earthquake (1923) is a well documented event, especially in P. Hadfield’s ‘Sixty Seconds That Will Change the World: The Coming Tokyo Earthquake’ [14 op. cit]. P. Hadfield draws on Japanese records to provide a detailed literary description of the event, of the domino effects

and the damage. The description highlights the complexity of a catastrophe of natural origin in an urban environment.

The major earthquake that struck the Kanto region on 1 September 1923 shortly before noon killed thousands and caused serious damage in the cities of Yokohama and Tokyo. The shock waves that lasted less than one minute destroyed two-thirds of Tokyo and four-fifths of Yokohama. Numerous fires broke out in both cities, because the event occurred when the inhabitants were beginning to warm their braziers and light their cookers to prepare meals. At the time, Tokyo, the capital of a little developed country, counted 2.5 million inhabitants. In Tokyo the braziers set light to the wooden houses, gas and hydrocarbon depots and tanks exploded, gas mains broke and the broken water mains made fire-fighting impossible. The mostly agricultural Japanese economy was badly hit. It was estimated that 9000 factories were destroyed by fire. More than 120 000 were killed either by buildings collapsing or by fires, or by crowd panic. As the fire in Tokyo could not be brought under control, to escape the advancing flames, many victims tried to cross the River Sumida that skirts central Tokyo. But when the bridge between the two banks broke, hundreds became panic-stricken and toppled into the water, where they met their deaths.

This account emphasizes both the speed of the event and the tragic consequences of the fires that broke out in Tokyo and Yokohama immediately after the earthquake. The traditional wooden buildings facilitated the outbreak of many fires [22].

B. Instantiation of the ontology

The ontology is instantiated in two stages by our method:

- specialization of generic concepts (element, event, damage) by specifying what types of elements, events and damage are spoken of in this story;
- development of an object diagram representing the account.

1) Specialization of the conceptual model

The first stage of the instantiation consisted in analysing the account of the ‘Great Kanto Earthquake’ to extract the terms that specialize the ‘Element’, ‘Event’ and ‘Damage’ classes (Figs 4 and 5). This analysis uses the generalization/specialization relation of concepts. For example, geological faulting is one sort of event; a bridge is one sort of infrastructure.

For the needs of the description, the concepts of ‘City’ and of ‘District’ will specialize the concept of systems (we consider them, then, as particular systems in that they are themselves made up of elements). This structuring/representation of information will enable us to understand the interleaving of the spatial levels and so the complexity of the spatial scale of a phenomenon: description at the scale of a city, a district or a set of districts making up a city (Fig. 4).

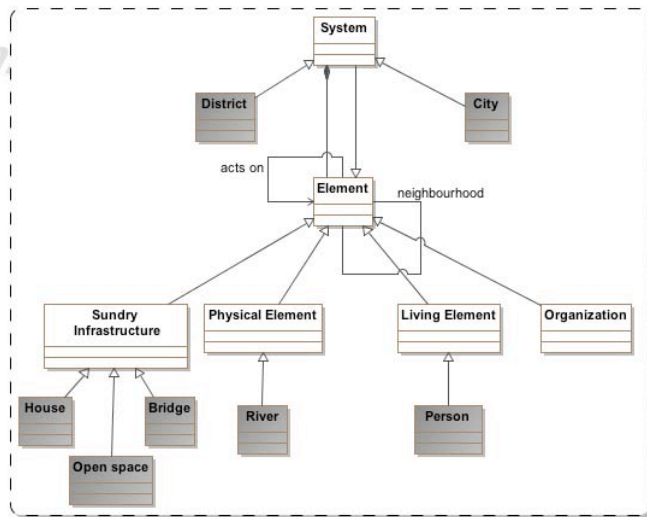


Fig. 4. Specialization of the system structure

The elements on which events bear are the 'House', 'Open Space' and 'Bridge' elements for the 'Infrastructure' class; the 'River' class for the class named 'Physical Element'; the 'Person' class for 'Living Element' (Fig. 4). The 'Faulting',

'Earthquake', 'Lighting Brazier', 'Fire', 'Collapse House', 'Assembly', 'Flight' and 'Crushing' classes specialize the 'Event' (Fig. 5).

The 'Human Damage' class is specialized into the classes 'Injury', 'Death', 'Injured' and 'Dead', while the 'Material Damage' class generalizes the 'Destruction House', 'Destruction Houses' and 'Destruction Bridge' classes (Fig. 5).

At this level of analysis, we can already see the complexity of the system explicitly appearing because of the variety and the number of components, the presence of individual and collective structures: the generic concept 'Human Damage' may concern one person (death, injury) or a population (dead, injured); the 'Material Damage' class may generalize destruction of a specific house or bridge or of several houses on the scale of a district or a city. Implicitly, complexity is also engendered by the interleaving of various levels of organization [Pavé, 1994]. The 'Assembly' class, for example, is the result of individuals clustering. We shall see later that such interleaving of levels is reflected by the emergence of new properties.

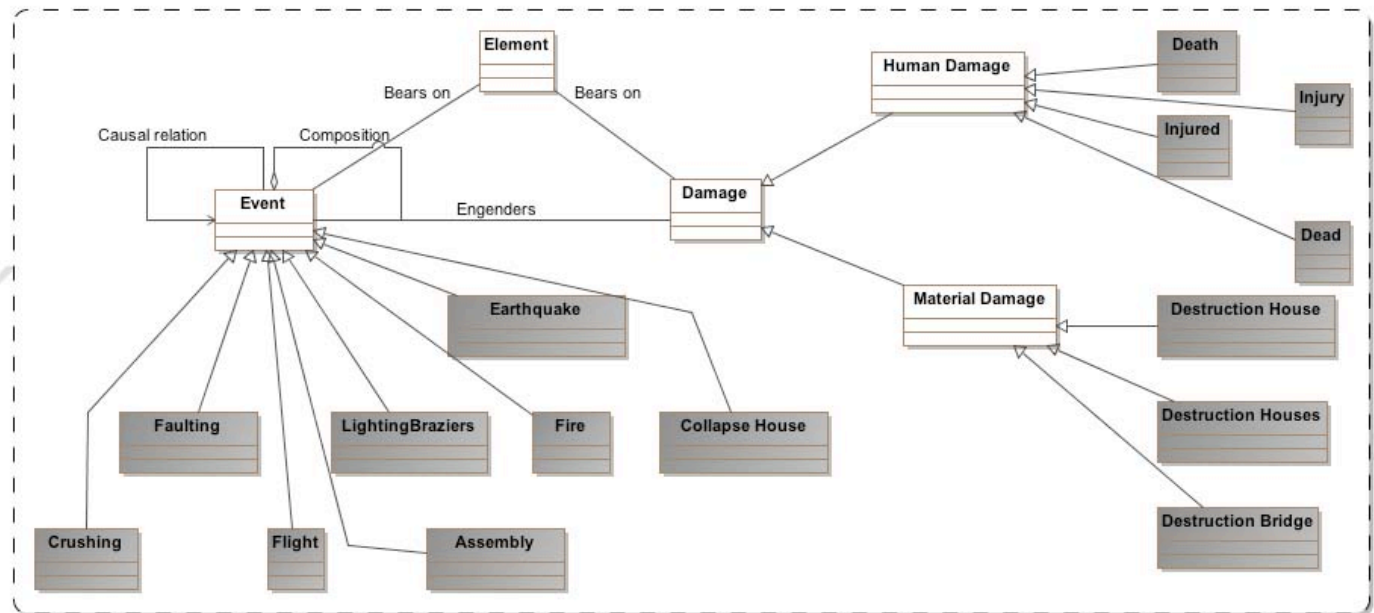


Fig. 5. Specialization of the system dynamics

It will be noticed that the complexity arising from the interleaving of spatial levels appears clearly in the system structure but is less directly apparent for events. This observation can be explained by:

- the actual composition of the ontology which means that events relate to structure;
- deliberately ignoring interactions governing each type of event. Such interactions usually give rise to new properties, especially in the field of catastrophes [20 op. cit.]. Each type of event identified is therefore the outcome of a process of interaction. To take an example, friction between tectonic plates engenders stress that builds slowly and eventually

causes a sudden release which, by domino effect and force transfer, may create another until a chain reaction is produced that is the origin of an earthquake [16 op. cit.].

2) The construction of the concrete model

To speak of the particular event of the 'Great Kanto Earthquake' we instantiate the abstract concepts identified generally in the conceptual model and more precisely in the specification of the model.

a) Representation of the spatial and temporal context

From P. Hadfield's account we extract information about the identification and situation of elements of the system in

space and their spatial arrangement. This information allows us to identify the general spatial context on which the events will bear. The instantiation of the ontology on the basis of the textual data allows us to consider a particular system composed of two cities, Yokohama and Tokyo. A neighbourhood relation (from the 'Element' class relation) is established between these two cities because Yokohama is located 'a few kilometres south-west of Tokyo' (Fig. 6).

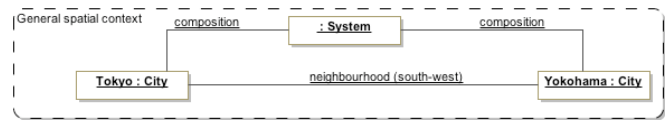


Fig. 6. The spatial context

These two cities experience a same event named the Great Kanto Earthquake. This event may, as need be, be considered as a point in time (1 September 1923) or as an episode, that is, in terms of its unfolding, its dynamics over time: from 11.58 am until sunset (Fig. 7).

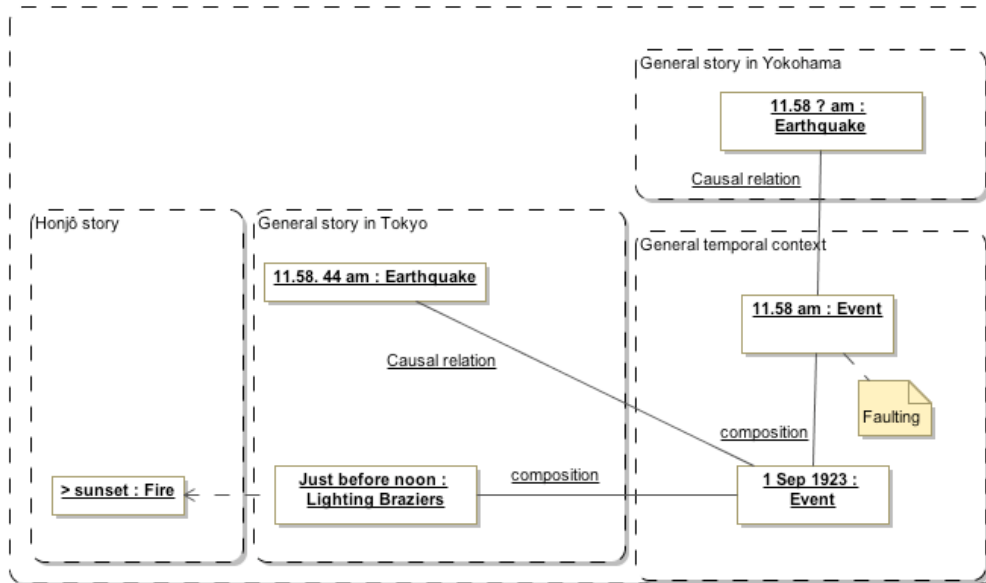


Fig. 7. The temporal context

b) Representation of the event at different scalar levels

Instantiation of the ontology allows us to account for the scales of analysis of the event and the variability in the fineness of the level of detail of the event depending on the selected scale level. Two examples are covered to further validate the ontology: the transition from the macro scale to the micro scale (analysis of the event on the scale of the city of Yokohama, then on the scale of one person), and the transition from the macro scale to the meso scale (analysis of the event on the scale of the city of Tokyo and then of its districts). The multiple scales of these two examples clearly show that the level of detail of the unfolding of the event varies with the spatial scale level selected for recounting the event. Instantiation of the account thus shows several changes of scale all providing clarifications about the unfolding of the catastrophe.

The visual representation (of the graphic modelling type) of this instantiation also helps to identify the multiple scales.

- (1) From the macro scale (city) to the micro scale (person): the transition from an overview to a close-up view of the event

Instantiation of the account allows us to distinguish the

general history of the earthquake that unfolds on the scale of the city of Yokohama (Fig. 8) and a particular story of one building and one person (Fig. 9). We thus have an overview and a close-up view of the unfolding of the event, enabling us to test one of the objectives of the ontology, the multi-scale analysis.

The event of 11.58 am, that we characterized as faulting, causes an earthquake at 11.58 am and that bears on the city of Yokohama. On the scale of the city of Yokohama, we learn that the earthquake is the cause of a domino effect, a fire. These two events engender material damage such as the destruction of housing, that has a bearing on the city (Fig. 8).

But in his account, Hadfield also describes the story of the earthquake on an individual scale. That is a particular story in Yokohama that retranscribes the event for a building (a restaurant) and a clearly identified person ('a pretty waitress') (Fig. 9).

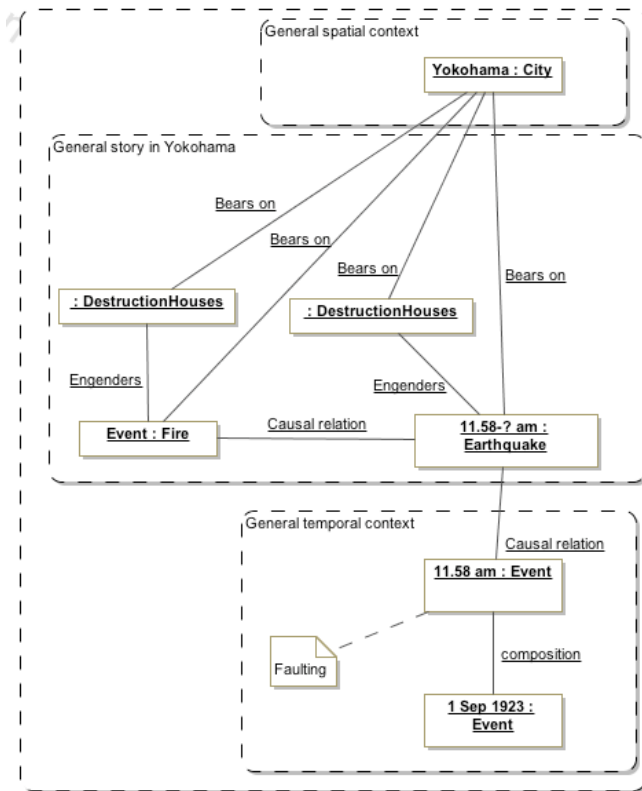


Fig. 8. Instance of the factual ontology: a general story in Yokohama

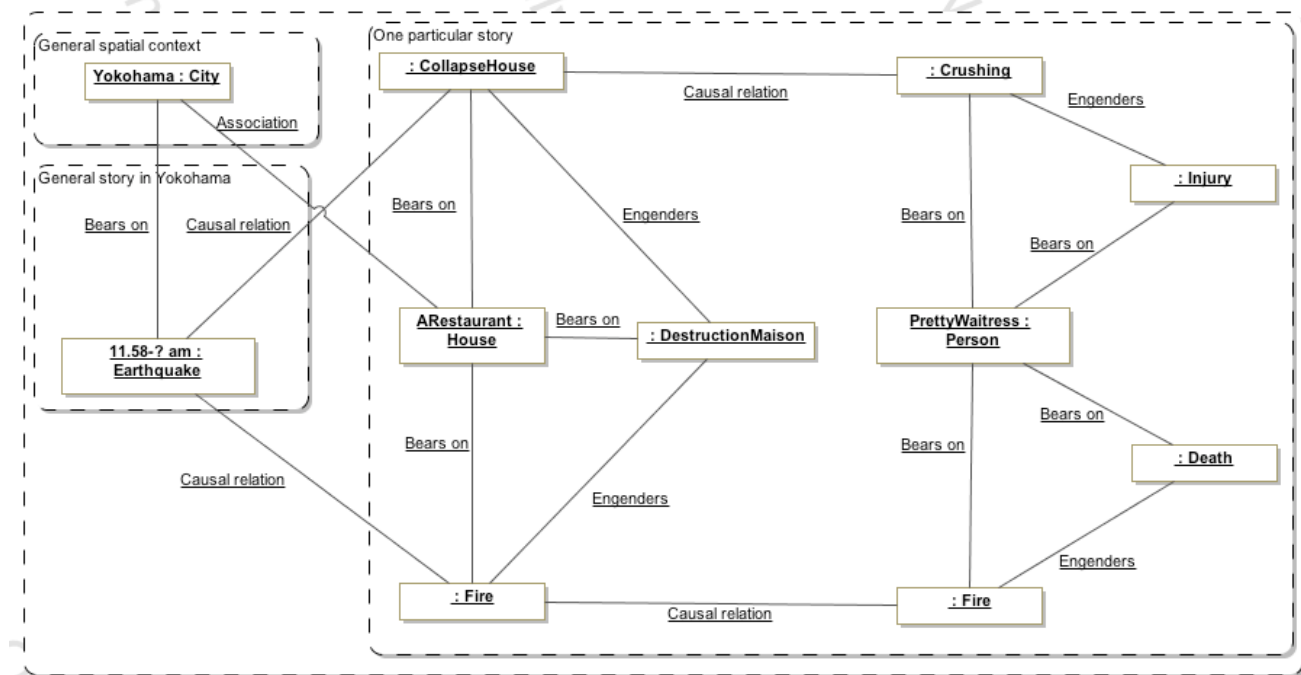


Fig. 9. Instance of the factual ontology: an individual story in Yokohama

The earthquake triggers two causal chains of events on the micro scale, a fire and the collapse of a house that bear on a restaurant and that engender damage of the 'House Destruction' class. That damage bears on a well identified establishment: a restaurant. The instantiation presented show therefore that we have a set of events that bears on individual

entities (a restaurant, a young girl) that engender damage that becomes more serious with time. The young girl is first injured by being crushed in the collapse of a restaurant, and then killed by a fire that breaks out inside the restaurant. This instance shows that the fatal injury results from the combination of several events.

This first instantiation allows us to validate the ontology on a multi-scale analysis, in this case the analysis at the macro scale and the micro scale. The example covered below also confirms the validation of the ontology for the transition from the macro to the meso scale and reveals the complexity of the system due to the interleaving of spatial levels.

- (2) The interleaving of spatial levels: analysis of the unfolding of the event on the scale of the city of Tokyo and its districts

Here the event is analysed at two levels: the city of Tokyo

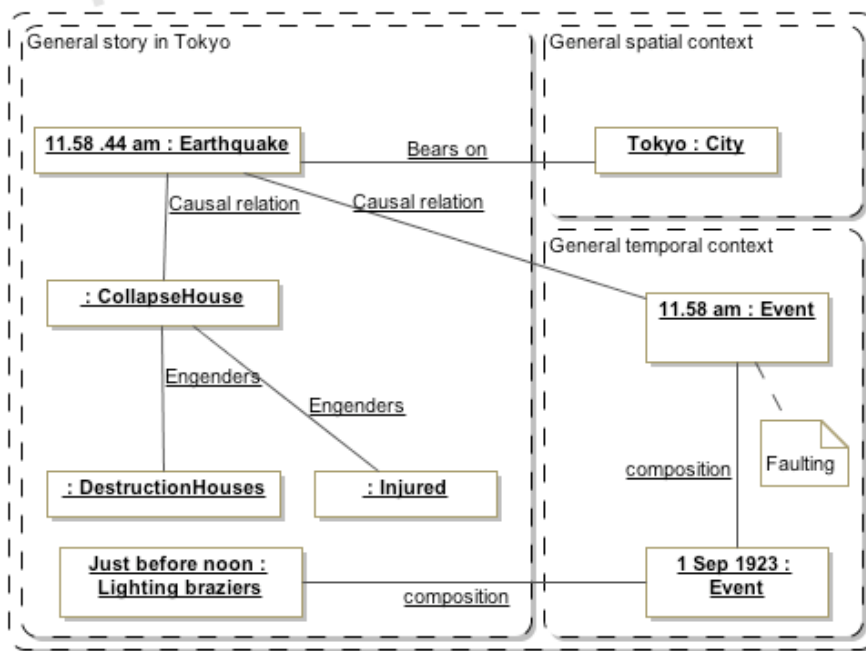


Fig. 10. The earthquake of 11.58 am and 44 seconds on the scale of the city of Tokyo

The story of the centre (Fig. 11) requires different types of event to be differentiated: the fire, the flight and the assembly. One bears on the open space of the Imperial Palace, the other on the open space of the River Sumida. The gathering of a crowd outside the Imperial Palace did not cause any human damage. However, the assembly that bears on the River Sumida was the scene of many human losses connected with a series of relations of contextual causality and panic behaviour. Those behaviours were part of a chain of causal relations between events (fire, flight, assembly) and a chain of perceptions (visual, auditory, etc.) of the situation. Those behaviours could not be transcribed in the factual ontology because the ontology in its current state does not provide the conceptual tools for dealing with perception.

(Fig. 10) and its districts (Figs 11 and 12).

The event (now characterized as the Great Tokyo Earthquake of 1 September 1923) is composed of two events that took place in one case at 11.58 am (the faulting) and just before noon (the lighting of the braziers). On the scale of the city of Tokyo (Fig. 10), two events are instantiated: the earthquake at 11.58 and 44 seconds and the collapse of houses. These events are part of a chain of events arising from the general temporal context. The 'Collapse House' event engenders two types of damage: material damage (destruction of houses) and human damage (the injured).

Instantiation of the story of Honjô (Fig. 12) highlights a contextual system comprising three districts—Nihonbashi, Asakusa, Honjô—and of the River Sumida which, because of their neighbourhood relation, triggered an event chain of fires in space and time (at 2.00 pm, 4.00 pm) entailing behaviours of flight and of assembly in an open space: a former army depot that had become wasteland. This space was not spared by the advancing fires. After sunset, a new fire broke out, bearing on the open space and engendering many human losses because of a factual causal relation between two events: the assembly brought about by the earlier fires and this new fire. There was therefore a series of events which, because of their diffusion in space and time, became multipolar.

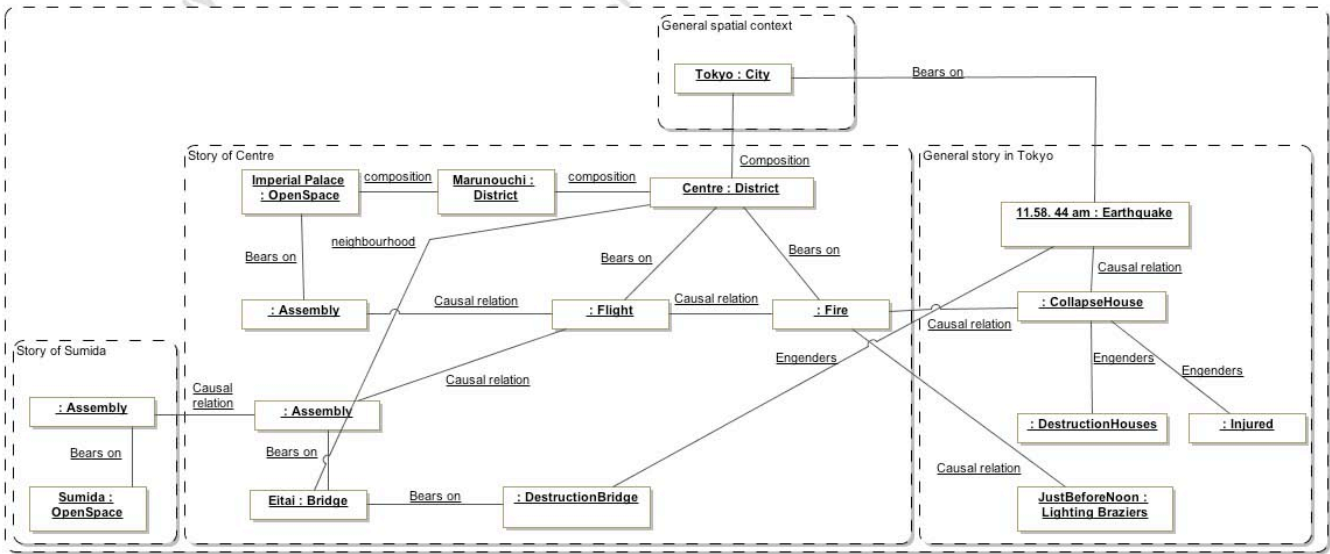


Fig. 11. Instantiation of the story of the Centre in Tokyo

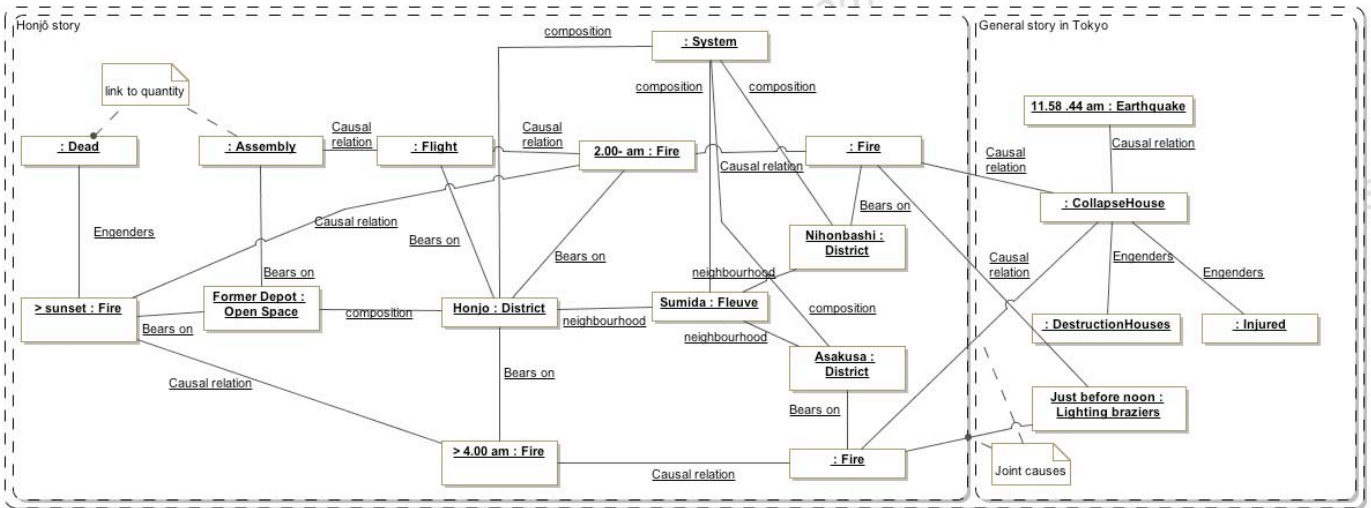


Fig. 12. Instantiation of the story of Honjō in Tokyo

Instantiation of this story shows that it is relatively easy to give an account of a catastrophe type of event using the factual ontology ‘filter’ proposed by [12 op. cit.]. Instantiation of the Great Kanto Earthquake has also showed the need for a multi-scale approach to reconstruct the account as well as possible because each scale provides specific information about the event. This vision of an event on different scales has many advantages in terms of comparison: comparison of accounts pertaining to different catastrophes, but also comparison of events of the same scale localized in different places and part of the same catastrophe.

IV. DISCUSSION

A first important element is that UML diagrams make it possible to visualize not just the articulation between concepts but also the structure of events and of concrete systems. For example, in the previous figure, the cascade of events, here the propagation of the fire, by making it clear which districts it

bears on, brings out a topology within the city of Tokyo that is never described as such in the account. The graphical representation brings it out quickly. In the same way, concurrent event chains appear that jointly contribute to a new event (e.g. the fire in the former depot) and the structural and event hierarchy that reciprocally make visible the implicit structures.

Whether the example of the Honjō district or that of the waitress in Yokohama (on very different scales), by following the ties between instances, the representation of the account brings out structurally, the domino effects that are often mentioned in the literature. More than domino effects, it is multiple effects by separate causal chains that allow us to account for events (and therefore for vulnerability) that would not otherwise be identifiable. The catastrophe therefore became multipolar and evolved in space and time.

The case of Honjō is especially interesting, for all of the districts involved, on either side of the river, only formed a system on the occasion of the events that occurred there. Three

points can be learned from this:

- the existence of particularly substantial vulnerability of a district that does not seem to have been identified as such;
- the relative vulnerability of the centre and of Honjô tied to the dynamics of the process that makes what are *a priori* similar elements -the imperial palace and wasteland on the site of a former depot- play very different roles since the population can take refuge there in one case and dies there in the other;
- the fact that a system does not necessarily exist *a priori* but is identified depending on the events that occur there. This highlights the interest of making simulations under various scenarios so as to identify the systems that emerge and their associated vulnerabilities. A system and its vulnerability do not exist of themselves but only as a function of the events that may occur there.

As concerns the validation approach itself, there are two points of interest. First, it has enabled us to complete the conceptual ontology, not just to add more specific concepts such as the idea of city or district, but also linkages we had not thought of *a priori* such as the neighbourhood relation and the hierarchical breakdown of systems. Conceptual ontology virtually acquires the status of theory, that can be revised after the experimentation constituted by the instantiation on a concrete case. It has also enabled us to show that the whole of a complex account through the diversity of the events described and its multi-scalar aspect could be represented (not everything has been presented here for reasons of space).

Admittedly, that does not prove that any and all accounts can be modelled with the concepts proposed, nor does it prove the relevance of these concepts to the other part of the conceptual ontology that is specific to the characterization of facts such as catastrophes by various criteria. There too, a mixture of tests of internal coherence and instantiation of accounts and multiple testimonies is required.

V. CONCLUSION AND PERSPECTIVES

Although it must still be subjected to other instantiations, whether in terms of structure and of system dynamics or in terms of the representation borne by actors on the event, the example proposed has allowed us to emphasize that factual ontology may provide a framework for formalizing knowledge and so facilitating comparisons. It has also shown the essential character of a multi-scale approach when accounting for an event. Lastly, it seems to us that instantiation provides insight into the timing of events on a given scale (it is not always specified in the account) and their spatiality.

At this stage, we cannot yet validate the ontology of risk and catastrophe proposed by [12 op. cit.] but this first instantiation has shed some interesting light on things. Other examples should be covered to confirm or possibly fine-tune the proposed ontology.

Nonetheless, although the instantiation teaches us a great deal, we are aware of the limits of the ontology in its current shape. Thus, the panic phenomenon referred to in the text titled 'The Great Kanto Earthquake', could not be treated in

the context of this ontology. Panic is part of a chain of causal relations between events (fire, flight, assembly) and a chain of perception (visual, auditory, etc.) of the situation. Panic is therefore dependent on a series of events but also on the perception people have of the event. The model proposed does not as it stands provide the conceptual tools for dealing with perception.

We need, therefore, to go beyond this limit because panic behaviour is not an epi-phenomenon. Panic is unusual in more ways than one: it is neither localized, nor confined to a particular environment, nor the result of any one specific event.

REFERENCES

- [1] A. Dauphiné, *Risques et catastrophes*. Paris: Armand Colin, 2003.
- [2] R. D'Ercole et al., "Les vulnérabilités des sociétés et des espaces urbanisés: concepts, typologie, modes d'analyse," *Revue de géographie alpine*, tome LXXXII, n°4, pp. 87-96, 1994.
- [3] C. Gilbert, "La vulnérabilité, une notion à explorer", *Pour la Science*, n° 51, pp. 116-120, 2007.
- [4] G.-Y. Kervern. *Éléments fondamentaux des Cindyniques*. Paris: Economica, 1995.
- [5] F. Leone, *Caractérisation des vulnérabilités aux catastrophes « naturelles » : contribution à une évaluation géographique multirisque*. HDR, Université Paul Valéry – Montpellier III, 2008.
- [6] V. November, "Le risque comme objet géographique", *Cahiers de géographie du Québec*, 50(141) pp. 289-296, 2006.
- [7] P. Pigeon, *Géographie critique des risques*. Paris: Economica, 2005.
- [8] D. Provitolo, "La vulnérabilité aux inondations méditerranéennes: une nouvelle démarche géographique", *Annales de Géographie*. pp. 23-40, 2007.
- [9] J.I. Uitto, "The geography of disaster vulnerability in megacities: a theoretical framework," *Applied Geography*, Tome 18, n°1, pp. 7-16, 1998.
- [10] Y. Veyret, *Les risques*, Paris: Bréal, 2004.
- [11] B. Wisner, "There are worse things than earthquakes: hazard, vulnerability and mitigation capacity in greater Los Angeles," in Mitchell J.-K., *Crucibles of Hazard: Disasters and Megacities in Transition*, Tokyo, New York, Paris: United Nations University Press, 1999.
- [12] D. Provitolo, J.P. Müller and E. Dubos-Paillard, "Vers une ontologie des risques et des catastrophes : le modèle conceptuel," in Actes du colloque, *Ontologie et dynamiques des systèmes complexes*, XVI èmes rencontres de Rochebrune, janv 2009, Available <http://gemas.msh-paris.fr/dphan/rochebrune09/papiers/ProvitoloDamien ne.pdf>.
- [13] T.R. Grüber, "Toward principles for the design of ontologies used for knowledge sharing", in N. Guarino and R. Poli (Eds.), *International Workshop on Formal Ontology*, Padova, Italy, (1993). In *International Journal of Human-Computer Studies*, Volume 43(5-6), pp 907-928, 2005.
- [14] P. Hadfield, *Sixty Seconds That Will Change the World: the Coming Tokyo Earthquake*. London: Sidgwick & Jackson, 1991.
- [15] S. Cranefield and M. Purvis, "UML as an ontology modelling language," in Proc. of the Workshop on Intelligent Information Integration, 16th International Joint Conference on Artificial Intelligence (IJCAI-99), 1999, Available: <http://www.aifb.uni-karlsruhe.de/WBS/dfe/iii99/cranefield-ijcai99-iii.pdf>
- [16] P. Bak, *How Nature Works*. New York: Springer-Verlag, 1996.
- [17] P. Blaikie, T. Cannon, I. Davis and B. Wisner, *At risk: natural hazards, people's vulnerability, and disasters*. London: Routledge, 1994.
- [18] C. Chaline and J. Dubois Maury, *Les risques urbains*. Paris: Armand Colin, 2004.
- [19] D. Provitolo, "Un exemple d'effets de dominos : la panique dans les catastrophes urbaines", *Cybergéo*, n° 328. 2005. Available: <http://www.cybergeoe.eu/index2998.html>
- [20] D. Provitolo "A proposal for a classification of the catastrophe systems based on complexity criteria," in *From System Complexity to Emergent Properties*, Springer, Series understanding complex systems, in press.

- [21] E. Daudé, D. Provitolo, E. Dubos-Paillard, D. Gaillard, E. Eliot, P. Langlois, E. Propeck-Zimmermann and Th. Saint-Gerand, "Spatial risks and complex systems: methodological perspectives" in From System Complexity to Emergent Properties, Springer, Series understanding complex systems, in press.
- [22] B. De Vanssay, "Du séisme de Kanto au séisme de Kobé. Utilité et limites de la prévision des catastrophes", *Futuribles analyse et prospective*, pp. 25-43, 1997.
- [23] A. Pavé A., *Modélisation en biologie et en écologie*. Lyon: Aléas, 1994.